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Development of normalization factors for Canada and the United States and comparison with European factors

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ABSTRACT

In Life Cycle Assessment (LCA), normalization calculates the magnitude of an impact (midpoint or endpoint) relative to the total effect of a given reference.
The goal of this work is to calculate normalization factors for Canada and the US and to compare them with existing European normalization factors. The differences between geographical areas were highlighted by identifying and comparing the main contributors to a given impact category in Canada, the US and Europe. This comparison verified that the main contributors in Europe and in the US are also present in the Canadian inventory. It also showed that normalized profiles are highly dependent on the selected reference due to differences in the industrial and economic activities. To meet practitioners' needs, Canadian normalization factors have been calculated using the characterization factors from LUCAS (Canadian), IMPACT 2002+ (European), and TRACI (US) respectively. The main sources of uncertainty related to Canadian NFs are data gaps (pesticides, metals) and aggregated data (metals, VOC), but the uncertainty related to CFs generally remains unknown. A final discussion is proposed based on the comparison of resource extraction and resource consumption and raises the question of the legitimacy of defining a country by its geographical borders.

1. Introduction

Life Cycle Assessment (LCA) is a holistic environmental assessment tool that allows the compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product or service throughout its life cycle, from cradle to grave, i.e. from resource extraction and transformation to final disposal, including production and use stages (Hauschild, 2005). It has been standardized by the International Standard Organization (see the ISO 14040 series (ISO, 2000)) and consists of four iterative phases: Goal and scope definition, Life cycle inventory (LCI), Life cycle impact assessment (LCIA) and Interpretation. In LCIA, impacts are evaluated through impact scores (S_i), which are results of multiplication between emission inventories and characterization factors (CFs). These impacts can be calculated either at a midpoint or an endpoint level: midpoints (e.g., ozone depletion potentials) represent an earlier link on the cause–effect chain prior to differentiating the individual impacts, or endpoints, (e.g., skin cancers) which might result from an environmental perturbation (Bare et al., 2000). Normalization is an optional element of the LCIA phase, which compares the magnitude of a potential impact (midpoint or endpoint) relative to the total effect of a given reference (ISO, 2006b). It has the advantage of expressing LCA results in respect to the relative importance of the selected reference. Normalization factors (NFs) can be associated to each impact category indicator, both at midpoint or damage level.

The normalized results are obtained as per Eq. (1):

$$N_i = \frac{S_i}{NF_i}, \quad (1)$$

where i = impact category, N = normalized result, S = impact score of a product, NF = normalization factor.

1.1. Choice of a reference system

Two different approaches can be used: internal normalization and external normalization (Norris, 2001). Internal normalization can be used in comparative LCA studies where one of the alternatives is selected as the reference. In external normalization, NFs are based on the total impacts of a reference system, for example a geographical

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area (region, country, continent or world). They can be expressed on an annual basis and in equivalents per inhabitant.

Few publications have already observed spatial variability when calculating NFs between different regions (Breedveld et al., 1999; Huijbregts et al., 2003; Sleeswijk et al., 2008). They have compared different sets of NFs at different geographical scales: the Netherlands, Western Europe, Europe (28 countries) and the World. In the end, they all arrived to similar conclusions: there are some similarities between the regions, e.g. a limited number of substances are responsible for the largest share of the impacts, but also differences related to the diverse economic and industrial activities of the geographical area.

The selection of a reference system to calculate NFs must be consistent with the system boundaries of the assessed product (Udo de Haes et al., 2002). Consequently, a global scale would theoretically be the best option for all products that travel worldwide. A drawback to this approach is the availability of world data: greenhouse gas emissions might be accessible at a global level (unfccc, 2009), but inventories of other substances like toxic chemicals are only available for some countries. Extrapolations can be used on various bases, but the correlations are rather weak (Sleeswijk et al., 2008).

While the regional or continental scale lacks the global economy coverage, it has the advantage of being consistent with national policy targets (Breedveld et al., 1999) and offers a wider range of available inventory data. Developing NFs at national and continental scales could be seen as a first step to obtaining global NFs. When the reference corresponds to a global scale, there is no difference between production and consumption. However, at a continental or national scale, the difference increases as imports and exports gain importance (Wilting and Ros, 2009). Even though consumption would theoretically be more suitable with assessed product system boundaries, the availability of emission data is higher in the case of production (Breedveld et al., 1999).

Current LCIA methodologies usually propose a set of NFs corresponding to the geographical area, i.e. production boundaries, for which the method has been developed. For example, IMPACT 2002+ (Jolliet et al., 2003), Ecoindicator 99 (Goedkoop and Spriensma, 2001) and ReCiPe (Goedkoop et al., 2009) propose NFs referring to the yearly average pollution generated by a European inhabitant, while TRACI (Bare, 2002) proposes NFs referring to the yearly average pollution generated by a US inhabitant. For the Canadian LCIA methodology, LUCAS (Toffoletto et al., 2007), no NFs have been developed so far.

1.2. Uncertainty evaluation

Managing uncertainty can help LCA practitioners to correctly interpret the conclusions of a study or to nuance them. As an example, a bias can be introduced by the normalization step if the normalization factor is too low, due to a lack of data or CF (Heijungs et al., 2007). Uncertainties and variability on NFs have only been qualitatively discussed so far. Two major sources of uncertainty are usually addressed: data gaps and uncertainty on CFs. Table 1 shows the level of uncertainty related to the NFs per impact category as defined by the authors in the literature.

Concerning data quality, the lack of emission data that particularly affect some groups of substances like toxic chemicals (e.g. pesticides, metals) (Breedveld et al., 1999; Huijbregts et al., 2003; Lundie et al., 2007; Sleeswijk et al., 2008), eutrophying substances (Huijbregts et al., 2003), ozone depleting substances (ODS) (Breedveld et al., 1999; Huijbregts et al., 2003; Sleeswijk et al., 2008), smog predecessors (Breedveld et al., 1999; Huijbregts et al., 2003) or ionizing radiation (Huijbregts et al., 2003; Sleeswijk et al., 2008) is often mentioned. Extrapolation can be used to fill these data gaps. Nevertheless, it introduces a new form of uncertainty due to the specificities and differences between regions (Huijbregts et al., 2003). Another issue is the completeness of the inventories that only report the emissions of a limited number of facilities. Some emissions, like hydrocarbons involved in photochemical ozone formation are also reported in vague terms (e.g. VOCs), whereas their photochemical ozone creation potentials vary up to 2.7 orders of magnitude (Huijbregts et al., 2003). Uncertainty due to missing CFs may introduce a bias in the NFs (Huijbregts et al., 2003); on the other hand, the related uncertainty of CFs is also reflected in the NFs. For example, uncertainty on CFs for toxic substances can reach 1.5 to 3 orders of magnitude (Rosenbaum et al., 2008).

In spite of these observations, no quantitative uncertainty and variability assessment has yet been performed on NFs to clarify what additional uncertainty is introduced by this optional LCIA step.

The goal of this work is to calculate NFs for Canada, the United States and North America (i.e. aggregation of Canadian and US results) for both midpoint and endpoint levels and to compare them with existing NFs for Europe while identifying reasons for observed differences. Finally, the sources of uncertainty are discussed in depth in a more qualitative way.

2. Methodology

While ISO guidance allows the calculation of normalization in various ways (ISO, 2006a), here normalization will be calculated from emissions and consumption of resource data at a global, continental or regional level, expressed on a yearly person basis. Eq. (2) is used to calculate NFs (Udo de Haes et al., 2002):

$$NF_i = \frac{\sum CF_s \times E_s}{P} \tag{2}$$

Where NF expresses the normalization factor (Person·years) for the impact category i, CF the characterization factor (Impact/kg) of a given substance "s", E the emissions of "s" on the given geographical area (kg/yr) and P the population of the territory (Persons). The characterization factors evaluate the impact contribution of an emitted substance to the environment for a given impact category.

Table 1
Overview of the level of uncertainty of existing NFs due to emission inventory data gaps and uncertainty of characterization factors according to the literature.

		Small	Moderate	High
Breedveld et al. (1999)		Global warming, acidification, energy depletion	Ozone depletion, smog formation, nutrification	Human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity
Huijbregts et al. (2003)	Data			Human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity, radiations (lack of data), eutrophication (extrapolation), smog formation (aggregated data)
	CF		Smog formation, acidification, terrestrial eutrophication (regionalization)	Human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity (lack of CFs, modeling)
Sleeswijk et al. (2008)	Data	Global warming, acidification, energy depletion, smog formation	Eutrophication	Human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity, radiations, ozone depletion, respiratory effects
	CF			Human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity (fate modeling)